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Decomposition of moss litter in a mature Scots pine forest

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With 3 figures

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1. Introduction

In many boreal forest systems where mosses cover the ground they represent a significant part of the biomass production and subsequently contribute to litter formation. In central Sweden figures of about 30—35 g m^{-2} yr^{-1} are common (Persson *et al.* 1980). Decomposition process and rate for this type of litter appears to be little known, a situation appearing to apply to all cryptogams (*cf.* Swift *et al.* 1979, Frankland 1974).

Changes in organic-chemical composition of litter during decomposition were previously described by Tenney & Waksman (1929) and Bengtsson (1936) for agricultural litters and by Berg *et al.* (1982) for needle litter. They determined that apart from the solubles, part of the arabinans were degraded readily, followed by cellulose and hemicelluloses. Decomposition of the sulfuric-acid lignin fraction started last and consequently this component exhibited a relative recalcitrance during the decomposition process.

It appears that in addition to other proportions of polymer carbohydrates the types of lignin found in mosses are different from those in higher plants (Ericksson & Miksche 1974, Lindberg & Theander 1952). This appears important as the lignin level together with nutrient level has been shown to act as a two-step regulating mechanism for the decomposition of Scots pine needle litter (Berg & Staaf 1980). Even within one system, different litter types have very different organic-chemical composition (Berg & Staaf 1981a), and it would be of value to be able to generalize the influences found to several litter types.

The present study was carried out within the Swedish Coniferous Forest Project and was designed to describe the decomposition process for moss litter and to possibly identify regulating factors. The use of *Sphagnum* moss ,a species not normally found in Scots pine stands provided a litter with a high degree of chemical contrast to that normally found.

2. Site description

The 120- to 130-year-old Scots pine stand studied is located at the SWECON research site, Ivantjärnsheden, Central Sweden (60° 49′ N, 16° 30′ E) at an altitude of 185 m on a flat area of deep glacifluvial sand sediments. The mean annual precipitation at a nearby village is 609 mm (1931—1960), and the mean annual temperature +3.8 °C. The length of the growing season is about 160 days. (Number of days with a daily temp. higher than 6 °C; Axelsson & Bråkenhielm 1980.)

The tree layer is exclusively composed of *Pinus silvestris* L. and has a density of 393 trees per ha and a height of 17—19 m. *Calluna vulgaris* and *Vaccinium vitis idaea* form a well developed field layer, and the bottom layer, completely covering the ground, is mainly composed of the mosses *Pleurozium schreberi* and *Dicranum polysetum* sv. together with *Cladonia* lichens. The most recent direct effect of forestry practices was a slight thinning in 1960. A more complete description is given by Axelsson & Brakenhielm (1980).

The soil profile is an iron podsol with a weakly developed bleached horizon (2–7 cm) and the humus type is a typical mor. A very loose litter layer (A_{00}), interwoven with living mosses and lichens, covers a humus layer (A_{01}–A_{02}) of 5–10 cm. The A_{01} (F) and A_{02} (H) horizons are almost indistinguishable from each other. The *p*H range is 3.9–4.2 in the humus layer and 4.6–4.8 in the upper mineral soil. The parent mineral material as well as the whole soil is considered to be very poor in essential nutrients. The C/N ratio of the A_{01}–A_{02} layer is 42.3.

3. Materials and methods

3.1. Litter collection and sample preparation

Moss litter (*Dicranum polysetum* sv.) was prepared from moss sampled from an area of about 40 × 40 m in the 120-year-old Scots pine stand. *Sphagnum* sp. moss was sampled from an area of about 1 × 1 m in a nearby bog.

From the moss plants were cut out with both live and dead parts a short piece (about 1.5 cm) around a death point. About half the piece was thus green to green-yellow and the other half brownish. To kill the living part the moss was heated to 50 °C overnight.

After drying at room temperature to obtain an even moisture level (about 4 % moisture) dry mass was determined at 85 °C and the largest difference in moisture content was less than ± 0.5 % of the average (n = 20). The litterbags, made of terylene net with a mesh size of about 1 mm, measured 8 × 8 cm. An amount of about 0.5 g of moss litter was enclosed in each bag.

3.2. Field incubations

The litter-bags were placed between the moss of the L-layer and the humus (FH)-layer in a measurement plot (1 × 1 m) in each of 20 blocks in a randomized block design (3 ha) in the 120-year-old stand.

The sets of litter-bags were laid out in the field in June 1977. Samplings were made 1–3 times annually during a four-year period (Table 1).

Table 1. Mass loss with time and nitrogen dynamics of total and lignin-associated nitrogen in *D. polysetum* and a *Sphagnum* sp. in a 120-year-old Scots pine forest

Date	Incubation time (days)	Mass loss (%)	Nitrogen			
			total		"lignin associated"	
			Rel. (%)	Abs (mg)	Rel.[1]) (%)	Abs (mg)
D. polysetum. Rate constant (k) 0.147 yr^{-1}; $p < 0.001$						
77-06-13	0	0 ( )	0.89	8.9	1.28	3.25
77-10-27	137	17.0 (1.63) A	1.07	8.9	1.30	2.78
78-05-22	344 (1 yr)	15.0 (1.11) B	1.11	9.4	1.29	2.93
78-08-31	445	21.9 (1.89) C	1.16	9.1	1.24	2.38
78-10-16	491	22.6 (2.05) D	1.11	8.6	1.39	2.96
79-05-30	717 (2 yrs)	25.5 (2.96) E	1.31	9.8	1.28	2.66
79-08-30	809	30.5 (4.01)	1.21	8.4	1.45	3.09
80-05-21	1,070 (3 yrs)	33.7 (2.75)	1.21	8.0	1.35	2.51
81-05-23	1,437 (4 yrs)	49.2 (4.57)	1.34	6.8	1.26	2.03
Sphagnum sp. Rate constant (k) 0.163 yr^{-1}; $p < 0.02$						
77-06-08	0	0 (—)	0.56	5.6	2.56	0.97
77-09-13	98	21.1 (0.65)	0.72	5.7	2.77	1.29
77-10-27	142	21.0 (0.78) A	0.67	5.3	3.09	1.50
78-05-22	349 (1 yr)	26.6 (2.44) B	0.66	4.8	2.01	0.82
78-08-31	450	22.9 (2.35) C	0.65	5.0	1.92	1.13
78-10-16	496	32.5 (3.93) D	0.70	4.7	1.62	1.18
79-05-30	722 (2 yrs)	33.1 (1.93) E	0.77	5.9	1.62	1.22

[1]) In per cent of the lignin fraction

[2]) A. Significant difference ($p < 0.05$)
B. Significant difference ($p < 0.001$)
C. Difference not significant
D. Significant difference ($p < 0.001$)
E. Significant difference ($p < 0.001$)

Note: Standard error in parenthesis. Letters indicate significantly different mass losses between species[2]).

On each sampling occasion one sample from each of the 20 plots in the stand was collected. The litter-bags were transported directly to the laboratory and cleaned of ingrown roots. After drying at 85 °C the samples were weighed individually and then pooled to one composite sample before the chemical analyses were carried out.

3.3. Chemical analysis

Composite samples were ground in a laboratory mill equipped with a 1 mm screen and the analyses were made at least twice. The amounts of water soluble and ethanol soluble substances were determined by sonicating the milled sample three times in a sonicator bath and weighing the samples after filtration and drying. The analyses for lignin (sulfuric-acid lignin as defined by the analysis method) and solid carbohydrates (xylan, mannan, galactan, rhamnan, arabinan, and cellulose) in the samples were carried out according to Bethge *et al.* (1971). The lignin fraction was also analysed for nitrogen content.

The release of water soluble substance for whole moss-litter samples was investigated on separate samples by allowing them to soak in distilled water at room temperature for 10 and 24 hours.

Milled samples of the initial material were also analysed for total contents of the elements C, N, P, K, Ca, Mg, Mn, and Na. All analyses were in duplicate. Carbon was determined by wet combustion by the method of Nõmmik (1971). Nitrogen was determined by a semi-micro Kjeldahl procedure (Nihlgård 1972). After an acid wet oxidation in $HNO_3 + HClO_4$, analyses were performed for sulfur by a turbidometric analysis as $BaSO_4$ precipitate (Blanchar *et al.* 1965), for phosphorus by the vanadate yellow-complex method (Jackson 1958) and for potassium by a flame photometric procedure. Calcium, magnesium, manganese and sodium were determined by atomic absorption spectrophotometry (Perkin-Elmer 403) in 1% LaCl-solution against acid standards (Pawluk 1967).

4. Results and discussion

4.1. Initial chemical composition

The concentration of nutrients was different in the *D. polysetum* moss as compared to other litter components in the L-layer of the mature Scots pine forest (Berg & Staaf 1981 a). Not only were the relative amounts higher but the ratios of phosphorus, sulfur, magnesium and potassium to nitrogen were 2–3 times higher in the *D. polysetum* moss litter than in needle litter from the same site (Table 2; Berg & Staaf 1980).

Comparing the *D. polysetum* and *Sphagnum* litters, it appears that the nitrogen, phosphorus, sulfur and calcium levels were lower in *Sphagnum*, whereas the percentage of potassium in *Sphagnum* was about double that in *D. polysetum* litter. The magnesium levels were essentially equivalent (Table 2).

The organic-chemical composition varied between the two moss species studied (Table 2). The water soluble part was lower for the litter of *D. polysetum* than for that of *Sphagnum* whereas the ethanol soluble part was about 1% in both cases — a figure which is low compared to most other litter components in this system (Berg & Staaf 1981 a). The *Sphagnum* lignin has been suggested to differ from lignin of higher plants (Lindberg & Theander 1952) and sometimes is called "protolignin" (Bland *et al.* 1968).

In a more recent study, Erickson & Miksche (1974) investigated several mosses and found no lignin in either a *Sphagnum* sp. or in a *Dicranum* sp. but did find other phenolic cell wall material. For the purpose of the present paper the term sulfuric-acid lignin is used even if not fully correct. The levels were about 4 per cent for *Sphagnum* and 25–26 for *D. polysetum*.

The relative amount of cellulose was higher (42 vs 27–29% in *Sphagnum* than in *D. polysetum* as was also the case for xylans (10 vs 3%). *D. polysetum* litter was lower in mannans (6.5 vs 12.4%) whereas the proportion of the other carbohydrates were similar.

4.2. Mass loss of the litter

The litter of *D. polysetum* decomposed with 15 per cent in the first year (Table 1). After two years about 25 per cent and after four years about 50 per cent were decomposed (Fig. 1). The *Sphagnum* litter had a somewhat higher rate initially but after some time the rate appeared to slow down and become similar to and possibly lower than that of *D. polysetum* litter. Nevertheless, after two years' incubation the accumulated mass loss was still higher than for the *D. polysetum* litter. Of the five samplings which were in common for the two moss

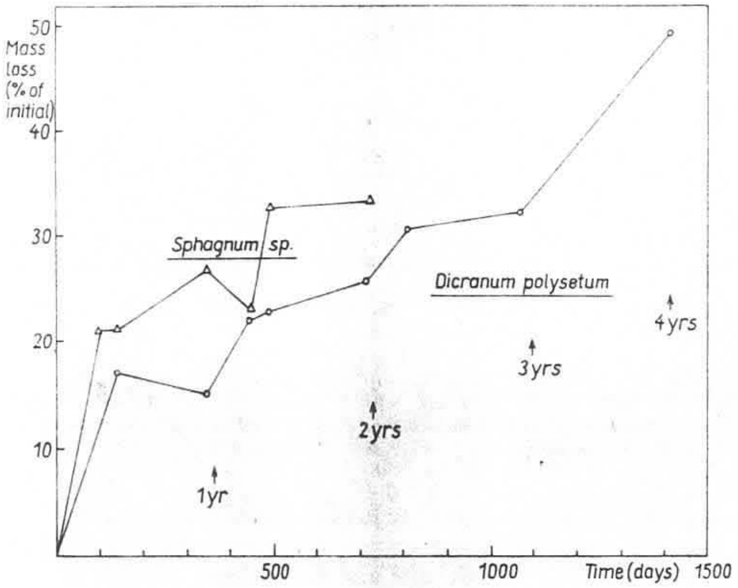

Fig. 1. Mass loss for moss litter incubated in the moss layer of a 120-year-old Scots pine *(Pinus silvestris)* forest. (○) *D. polysetum* litter; (△) *Sphagnum* sp. litter.

spp. accumulated mass loss was significantly higher at four measurements for the *Sphagnum* moss (Table 1). The mass loss followed a first order kinetics (Olson 1963) fairly well (Table 1) with $p < 0.001$ for the set of *D. polysetum* moss and $p < 0.02$ for the *Sphagnum* litter.

When comparing decomposition taking place in two separate periods, namely 0—12 months we found a significantly higher rate for *Sphagnum* in the first year. In the second year the mass loss rate had changed and *Sphagnum* lost 8.6 per cent and *D. polysetum* 12.4.

It thus appears that there was no direct relation between nutrient level and the early (first year) mass loss between the two moss types. This study thus does not support the model for changing regulating factors suggested by Berg & Staaf (1980) where the nutrient level has a direct influence on the decomposition rate of the non-lignified tissues whereas the decomposition rate of lignin determines the rate of the lignified part. One possible explanation is the fact that the level of solubles was considerably higher in the *Sphagnum* samples and that the influence of nutrient level on mass loss rate was not as great as was the influence of solubles. It is possible that the high level of sulfuric-acid lignin of *D. polysetum* as compared to the *Sphagnum* litter may have influenced the rate in the early stages, as decomposition of the sulfuric-acid lignin started during the first winter. On the other hand was the decomposition about similar in the second year (not significantly different) in spite of the much higher lignin level of *D. polysetum* litter.

It should be noted that in spite of relatively high levels of nutrients, loose structure and — at least in *Sphagnum* — a very low sulphuric-acid "lignin" level, the decomposition was much lower than for Scots pine needles incubated in the same system (Berg 1981, Berg *et al.* 1982). Thus the rate constant (k) (Olson 1963) for *Sphagnum* was only 0.163 and for *D. polysetum* 0.147 (Table 1) compared to about 0.300 for needles. This was calculated over the same time period, and indicates almost half the rate for the mosses.

4.3. Chemical changes

The rather fast initial mass loss taking place in the first summer for both litter types probably was not due to leaching as no leaching was found from these litters in laboratory measurements ($< 2\%$) but it was more likely that a fast decomposition took place within the

Table 2. Initial organic-chemical and inorganic-chemical composition[1]) of the mosses, *D. polysetum* from a Scots pine stand and a *Sphagnum* sp. studied for comparison

Moss type	Carbon	Nitrogen		Phosphorus	Sulphur	Potassium	Calcium	Magnesium	Manganese	Sodium
		Total	Associated to lignin							
A. Concentration (mg g^{-1})										
Dicranum polysetum	488	8.9	3.2	0.90	1.01	4.67	2.20	0.60	0.48	0.11
Sphagnum sp.	n.d.	5.6	2.6	0.52	0.87	9.50	1.28	0.59	n.d.	n.d.

Moss type	Water solubles	Ethanol solubles	Lignin	Cellulose	Xylan	Mannan	Galactan	Arabinan	Rhamnan
B. Concentration (%)									
D. polysetum	*11.2*	*1.2*	*25.2*	*27.6*	*3.3*	*12.4*	*11.7*	*3.3*	*4.0*
Sphagnum sp.	*17.9*	*0.6*	*3.8*	*41.6*	*9.5*	*6.8*	*13.2*	*2.1*	*4.6*

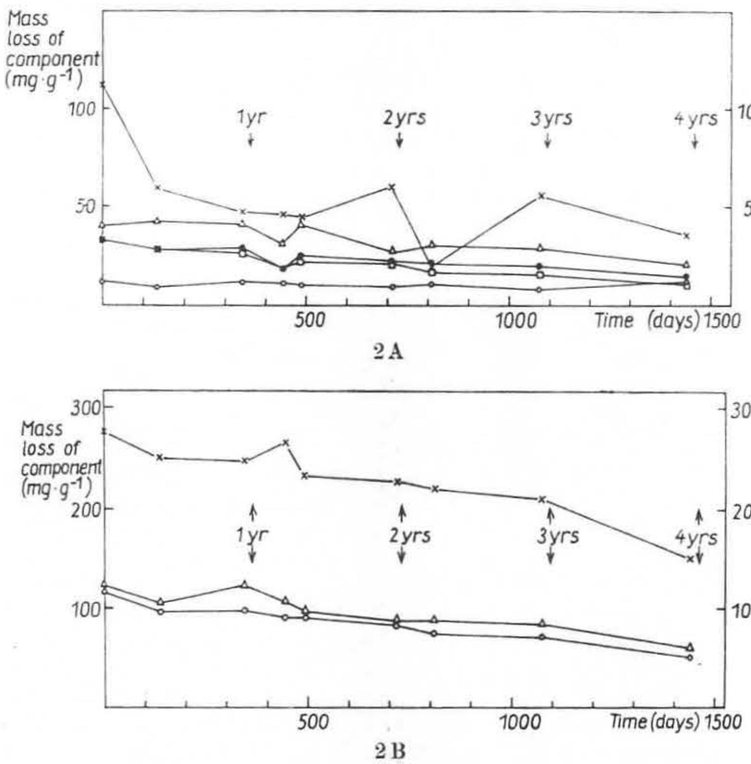

Fig. 2. Decomposition of some organic-chemical components of *D. polysetum* litter incubated in the moss layer of a 120-year-old Scots pine forest. A: (×) water solubles; (○) ethanol solubles; (△) rhamnans; (□) arabinans; (●) xylans. B: (×) glucans; (○) galactans; (△) mannans.

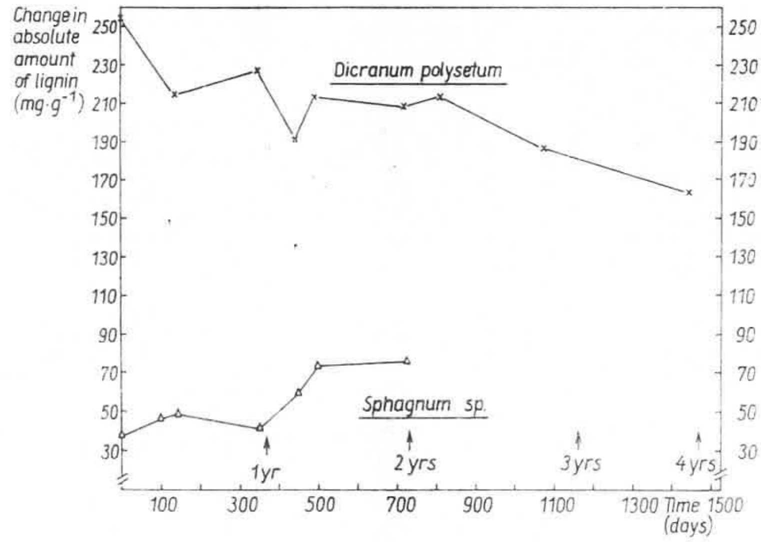

Fig. 3. Changes in amount of sulfuric-acid lignin in litter from *D. polysetum* (×) and a *Sphagnum* sp. (△) during decomposition in the moss layer of a 120-year-old Scots pine forest.

structure. In the first 137 days' decomposition of the *D. polysetum* litter it was seen that a large part of the water solubles was degraded (Fig. 2). In contrast to, for example, needle litter, the ethanol soluble part was very small (Berg et al. 1982) and the change in this fraction was also very small. Some of the polymer carbohydrates like the arabinans, glucans, galactans and mannans were also partly degraded during the first four months. A large part of the sulfuric-acid lignin was decomposed which, compared to needle litter, was somewhat unexpected (Fig. 3). It is also noteworthy that there was no absolute increase in this analytical fraction in the early stages of decomposition, an observation which has been commonly made with needle-litter lignin (Berg *et al.* 1982). The type of "lignin" found in moss has been described for *Sphagnum* (Bland, Logan & Menchun 1968), and a *Dicranum* sp. (Erickson & Miksche, 1974) and has been suggested not to be lignin at all but other types or aggregated phenols. In contrast to the sulfuric-acid lignin fraction of *D. polysetum* litter that of *Sphagnum* had a strong absolute increase from 38 to 75 mg/g during the decomposition period studied. The initial concentration was in this case considerably lower — only about 4 per cent compared to about 25 for *D. polysetum* and increased from about 4 to 11 per cent in the two-year period. The fact that the analytical sulfuric-acid lignin fraction had such a strong absolute increase in the *Sphagnum* moss (increase linear to mass loss, $p < 0.05$) should be interpreted with care. It is possible, though, that the increase could be due to different condensation products which were registered as "lignin".

For *D. polysetum* the relative increase in lignin in four years was from 25 to 32%. It appears, though, that this fraction was the only one increasing relatively and its decomposition rate was lower than those of the other fractions analysed.

After the decomposition in the first summer the fraction of water solubles remained rather constant both in the *D. polysetum* and the *Sphagnum* moss. The ethanol soluble fraction was rather small initially and the amounts remained fairly constant for up to four years' incubation (Fig. 2). There were large similarities between the two species regarding decomposition of carbohydrates. The rhamnans fraction, which was large for the mosses as compared to other ecosystems components (Berg & Staaf 1981a), was degraded at about the same rate, as was the whole litter. The other hemicelluloses were degraded at a somewhat higher rate in *Sphagnum*, especially the arabinans fraction which was degraded by about 50%. The glucans fraction had the lowest rate with about 20% in two years.

The dynamics of both total nitrogen and "lignin"-associated nitrogen in the *D. polysetum* litter differed slightly from what could be expected from the studies of needle litter (Table 1). In spite of the comparatively high initial nitrogen level, no net release took place (*cf.* Berg & Staaf 1980, 1981 b, Berg & Ekbohm 1983). The absolute amount of nitrogen remained rather constant for three years and a release started first in the fourth year. For *Sphagnum* no accumulation took place in spite of its lower initial level (Table 1). The relative amount increased all the time, however, and was linear to mass loss with $p < 0.01$ and $p < 0.02$ respectively for *D. polysetum* and *Sphagnum*.

The nitrogen associated to the sulfuric-acid lignin also behaved differently from that in needle litter (Berg & Staaf 1981 b) where this fraction increased both relatively and absolutely before a release took place. In the mosses no such relative increase was seen (Table 1) and the amount was rather constant for both *Sphagnum* and *D. polysetum* in the incubation period. In the latter a release started in the third year. The relative amounts showed no tendency either to decrease or increase, whereas for the *Sphagnum* litter mainly a decrease took place.

5. Concluding remarks

It appears that the decomposition rate of the moss litters was low and among the absolutely lowest for this system (Berg 1981). Such a finding was done also by Mikola (1954) who in laboratory measurements found litter from some mosses (among others *Pleurozium schreberi* and *Hylocomium splendens*) to be the most slowly degraded components of the 18 investigated. Our result was unexpected with regard to loose structure, and comparatively high nutrient levels (Berg & Staaf 1980) and, for *Sphagnum*, also the low level of both sulfuric-acid "lignin" and ethanol solubles. We may speculate, however, about the possibility of some compounds active as inhibiting agents. The mass loss from mosses appears at least partly to be regulated by levels of other chemical components than is mass loss from e.g. needle litter.

Due to the low decomposition rate, moss litter and humus fractions originating from the moss will constitute a relatively high fraction of the total amount of the organic layers. With an estimated yearly input of about 33 $g\ m^{-2}\ yr^{-1}$ and an assumed even litter formation over the year we would obtain at "steady state" an amount of about 230 $g\ m^{-2}$ of litter and litter remains. For needle litter with an average yearly input of 97 g, an assumed litter input only once a year and a rate constant of about 0.30, the corresponding figure will be about 320 $g\ m^{-2}$ (Olson 1963). This means that moss litter contributed more than twice as much to the organic layer than the same amount of needle litter would have.

In their investigation on litter components in the forest floor Staaf & Berg (1977) found that of a total amount of 697 $g \cdot m^{-2}$ of dead organic material in the L-layer identifyable moss litter constituted 10% (68 g) and needle litter 23% (156 $g\ m^{-2}$). There was also a fraction of miscellaneous material which was not possible to identify making up 30% (208 $g\ m^{-2}$). In the same sampling the amount of organic substance in the humus layer (roots excluded) was measured to be 1,540 $g\ m^{-2}$. Provided that the calculations are correct this would mean that about $^2/_3$ of the moss litter should be non-identifiable as compared to about half the amount for needle litter.

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Synopsis: *Original scientific paper*

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Decomposition of two moss species, namely *Dicranum polysetum* and a *Sphagnum* sp. was followed for three years in a mature Scots pine forest. The rate constant (k) was about 0.12—0.16 or half that of Scots pine needle litter at the same site. Between the species nutrient level did not affect mass loss rate, nor did the level of sulfuric-acid lignin. The changes in organic-chemical components were followed, namely sulfuric-acid lignin and the polymer carbohydrates cellulose, mannan, galactan, xylan, arabinan and rhamnan.

Key words: moss litter, decomposition, Sphagnum, Dicranum.